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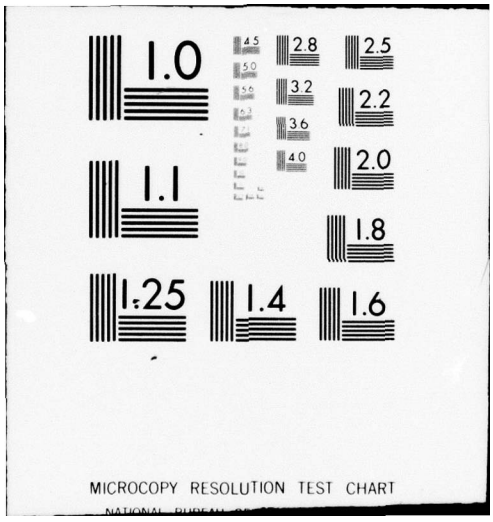
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(9) FINAL TECHNICAL REPORT FOR PERIOD

1 SEP 77 - 28 FEB 79

by

(10) Laveen N. Kanal

Principal Investigator

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Abstract (contin

ptimizing the decision policies at the nodes of a decision tree. Also described are contributions to the modeling of communication channels with memory and the investigation of models of database query languages.

Among the papers published on the research performed under this grant, the following two papers present substantive overviews of the research and place the work in the perpective of other contributions in the areas discussed. Both papers include extensive lists of references. The two papers are: Laveen N. Kanal, "Problem-Solving Models and Search Strategies for Pattern Recognition" IEEE Trans. on Pattern Analysis and Machine Intelligence, vol. 1, No. 2, p.193-201, April 1979; and Laveen N. Kanal, & A.R.K. Sastry, "Modeling Channels with Memory and their Applications to Error Control", Proc. of the IEEE, vol. 66, No. 7, p. 724-744, July 1978.

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Problem-Solving Models, Pattern Analysis, Classification, Feature Extraction, Non-Directional Structural Analysis, Parallel Search Algorithm, Modeling Channels with Memory, Modeling DAta Base Query Languages.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
The report summarizes research progress under this grant and lists the papers reports and presentations given during the period 1 Sept. 77-28 Feb.79. New approaches to search and extraction of structure in patterns which include a non-directional parallel search algorithm which has been shown to be better than the alpha-beta search algorithm when dealing with game trees. New methodology for the design of hierarchical statistical classifiers includes use of state-space ordered search algorithms and introduction of heruistics to cut down the number of decision rules to be tried in a dynamic programming approach to → next page
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Grant AFOSR 76-2901B

FINAL TECHNICAL REPORT FOR PERIOD

1 SEPT. 1977 - 28 FEB 1979

Research performed under this grant during the period 1 Sept. 1977 to 28 Feb. 1979 can be categorized under the following topics:

1. Contributions to Pattern Analysis and Classification.

1.1 New approaches to Search and Extraction of Structure in Patterns.

1.2 New Methodology for Statistical Classification.

2. Contributions to Modeling Communication Channels with Memory : Extensive Survey summarizing research performed by ourselves and others on Modeling Communication Channels with memory.

3. Modeling and Analysis of Data Base Systems.

3.1 Investigation of Models of Data Base Query Languages.

## Summary of Progress

Some desired objectives for a structural pattern analysis procedure are: 1) pattern analysis should be able to proceed in a bidirectional data-directed and model-directed manner with primitive extraction and structural analysis coupled; 2) the analysis should not be restricted to a cannonical left-right scan of the entire data but should be non-left-right, selective, and

focus on prominent morphs; 3) multiple and ambiguous interpretations should be developed on a best-first basis, with ambiguity permitted in both segmentation and structural analysis.

A structural analysis paradigm which realizes the above enumerated objectives-not satisfactorily addressed previously-was developed with partial support of this grant and reported in the PhD dissertation of Stockman [1977]. This nondirectional approach begins by identifying certain prominent primitive components which can be reliably extracted and then uses model-directed, data-confirmed search for the remaining pattern structure.

Because of the correspondence between Context-Free Grammars and AND/OR graphs, the new nondirectional analysis algorithm can bw viewed either as a "problem solver" or a parser. When applied to game trees, the algorithm is competitive with although different from the $\alpha$-$\beta$ tree pruning procedure in efficiently producing the minimax solution tree.

A topic left incomplete in the above work (done under this grant in the preceeding period) was the analysis of the performance of the non-directional analysis algorithm and its comparison with $\alpha$-$\beta$ search for evaluation of mini-max trees. During the current grant period, further work was done on this topic leading to the submission of a paper entitled "A Minimax Algorithm Better than $\alpha$-$\beta$ ?" by G. Stockman which has been accepted for publication in Artifical Intelligence. The

paper shows that the new algorithm SSS* is more efficient than $\alpha$-$\beta$ in the sense that SSS* never evaluates a node that $\alpha$-$\beta$ can ignore. Moreover, for practical distributions of tip node values, SSS* can expect to do strictly better than $\alpha\beta$ in terms of average number of nodes explored. In order to be more informed than $\alpha$-$\beta$, SSS* sinks paths in parallel across the full breadth of the tree. The penalty for maintaining these alternate search paths is an increase in storage requirements relative to $\alpha\beta$. (Some execution time data indicates that in some cases the tradeoff of storage for execution time may be favorable to SSS*.) Once again, a classical tradeoff between storage space and execution time has been achieved.

Additional analyses of the "average" performance of SSS* have been done during this period. It seems likely that a hybrid SSS* - $\alpha\beta$ procedure would be worthwhile. could be used to a certain depth to avoid SSS* storage problems, and then SSS* could be used effectively to save on tip evaluations. Alternatively SSS* could be used at the shallow level and at deeper levels of the tree.

Under the category of new methodology for Statistical Classification and Modeling, research continued on the Synthesis of Multistage Multiclass Classification Structures. In our earlier work, ordered search algorithms for S-admissible and B-admissible strategies for multiclass pattern classification were introduced and developed. Under the present grant, as

detailed in Kulkarni and Kanal(1978), it was shown that for certain parametric probability functions it is possible to derive tight bounds on the class accessible from a given node in the state space graph representation of the classification tree. The paper also shows, by example, how admissible search of a state-space graph for classification improves on the usual decision tree approach (in which after reaching a terminal, no logical strategy exists for reconsidering classes possible discarded earlier).

In an M.S. thesis [A. Dandapani, 1979], we have further investigated the Bayes-Admissible version of the B-admissible Search Strategy and also experimented with the heuristics for clustering decision rules and defining efficient decision rules developed in our earlier research on hierarchical classifiers.

A phased approach to tree design involves procedures for the specification of (a) a tree skeleton or hierarchical ordering or the class labels, (b) a feature assignment, i.e., the choice of feature(s) to be measured at each non-terminal node, and (c) the decision rule to be used at each non-terminal node. Even for reasonable size multistage multiclass problems, an optimal tree design by exhaustive search of all the above three aspects is not feasible.

Assuming that we have obtained the tree structure and the features to be used at each node, an optimal decision policy at each node can be obtained from a dynamic programming

(DP) procedure. In our earlier work under this grant, we introused the heuristic concept of an "efficient" decision rule to enable us to reject a large number of rules prior to their use in a DP procedure. Also, groups of decision rules known to be dominated by a given rule could be rejected through a branch and bound technique without having to evaluate the performance of each rule individually.

The thesis [Dandapani, 1979] and the paper [Dandapani & Kanal, 1979] report experimental results using leukocyte data, showing respectively, (1) the improvement in classification performance on indepent test samples, when a decision tree is searched as a state space suing the B-admissible strategy and (2) the reduction achieved in decision rules by using the "efficient" decision strategy in desgining a decision tree classifier.

In the area of modeling communication channels with memeory, we basically wrapped up the research performed by us on this subject under AFOSR sponsorship by writing an extensive survey and commentary [Kanal & Sastry, 1978] covering the significant work in the field. The paper examines the work done on channel models in the perspective of the applicability to error control.

Work on the development of a theory for doing logical inference on data bases was initiated during this grant period [Jacobs and Lavine(1978), TR699]. A formal theory for relational

databases was developed using the theory of models from mathematical logic. Criteria were established for determining the querying power of query languages. We also worked on the early stages of a project to develop a comprehensive logical model for databases which included as a special case relational, hierarchical, and network databases. The three standard types of queries, logical queries, query by example, and query by algebra, were extended to cover all three types of data bases and the equivalence of the three types of query languages was proved. This area of our research has as its goal the development of inference techniques for probabilistic hypothesis evidence database networks.

PAPERS, REPORTS, AND PRESENTATIONS related to Research
for period 1 Sept. 1977 - 28 Feb. 1979

Papers

Kanal, Laveen N., (1977) "Hierarchical Classifier Theory and Interactive Design", p. 301-322, in P. Krishnaiah (ed.), Application of Statistics, North Holland Publishing Co., Dec. 1977.

Kanal,Laveen N. (1977), "Some Current Concepts and Problems in Pattern Classification and Feature Extraction", Bull. Int. Stat. Inst. Dec. 1977, XLVII(2), p. 464-488.

Kanal, Laveen N., (1979) "Problem Solving Models & Search Strategies for Pattern Recognition", IEEE Trans. on Pattern Analysis & Machine Intelligence, Vol. 1, no. 2, pp. 193-201, April 1979.

Kanal, Laveen N. and A.R.K. Sastry(1978), "Models for Channels with Memory and their Applications to Error Control", Proceedings of the IEEE,Vol. 66, No. 7, pg. 724-744, July 1978.

Kulkarni, Ashok V., Kanal, Laveen N. (1978) "Admissible Search Strategies for Paramteric and Nonparametric Hierarchical Classifiers", Proc. of Fourth Intern. Joint Conf. on Pattern Recognition, Nov. 1978.

Lemmer, John, F. (1977), "A return to Probabilities in Computer Assisted Medical Diagnosis", in Proc Internl.Conf. on Cybernetics and Society, Sept. 1977, pp. 612-616, IEEE Catalog No. L77CH1259-ISMC.

Stockman, George, (1977), "Non-Directional Structural Pattern Recognition Using a Problem Reduction Representation" in Proc. Internl. Conf. on Cybernetics and Society, Sept. 1977, p. 601-604. IEEE cat. # L77CH1259-SCMC.

Stockman, George(1978), "Defining and Extracting Waveform Primitives for Linguistic Analysis" in Proc. of Fourth Internl. Joint Conf. on Pattern Recognition, p601-604, Nov. 1978.

Stockman, George(1979), "A Minimax Algorithm better than Alpha-Beta", accepted for publication in a 1979 issue of Artificial Intelligence.

# PAPERS, REPORTS, AND PRESENTATIONS

## Reports

Dandapani, Ajit (1979), Hierarchical Classifier Approach to Leukocyte Classification, Master of Science these, Submitted February 1979.

Dandapani, Ajit and Laveen Kanal (1979), "Selecting 'Efficient' Decision Rules in Designing Decision Tree Classifiers: Some Experimental Results", Report, Lab for Pattern Analysis, Dept. of Computer Science, U. of MD, submitted for publication April 1979.

Jacobs, Barry, and David Lavine (1978), On Completeness of Database Query Languages, Computer Science Tech. Rept. 699, Univ. of Maryland, College Park, Nov. 1978.

Kanal, Laveen N., Some Current Concepts and Problems in Pattern Classification and Feature Extraction, Computer Science Tech. Rept. TR-640, Univ. of Maryland, College Park, April 1978.

## Presentations

Kanal, Laveen N., "Research on Hierarchical Classifiers and Interactive Pattern Analysis" talks presented at: Dept. of Biomedical Engineering, Univ. of Missouri, Columbia, October 17, 1977, Dept. of Computer Science, Univ. of Nebraska, Lincoln, October 20, 1977, Dept. of Electrical Engineering, Univ. of Southhampton, Southhampton, England, November 30, 1977.

Kanal, Laveen N., "Some Current Concepts and Problems in Pattern Classification and Feature Extraction:, invited talk on December 9, 1977 at 41st meeting of the International Statistical Institute, New Delhi, India.

Kanal, Laveen N., talks on research at Indian Statistical Institute, New Delhi, during December 1977.

Kanal, Laveen N., "Current Pattern Recognition Research relevant to Remote Sensing", talk to Remote Sensing Division, Indian Space Research Organization (ISRO), Ahmedabad, India, December 26, 1977.

Kanal,Laveen N. "Fundamentals of Pattern Classification", talk to beginning graduate class, Department of Math and Statistics, Gujrat University, Ahmbabad, India, Deceber 27, 1977.

## PAPERS, REPORTS, AND PRESENTATIONS

Kanal, Laveen N., "*Machine Recognition of Patterns:* Potential for Societal Applications", Invited Fifth Anniversary Distinguished lecture, ISRO, Ahmedabad, India December 27, 1977.

Kanal, Laveen N., "Descriptive and Generative Models for 0-1 Processes and their Application to Communication Channels with Memory", talk to Communications Division, ISRO, December 28, 1977.

Kanal, Laveen N., Lectures on research on Interactive Systems for Pattern Analysis, Problem Solving and Pattern Recognition and on Severe Storm Pattern Recognition, at Indian Institute of Science, Bangalore, Jan. 10-12, 1978.

Kanal, Laveen N., Talk to Indian Institute of Technology, Madras, January 16, 1978, on pattern recognition research being done in our laboratory.

Kanal, Laveen N., Talk on pattern recognition research to Computer Science Department, Jawaharlal Nehru University, New Delhi, January 20, 1978.

Kanal Laveen N., "Problem Solving Search Models for Pattern Recognition", paper presented to the IEEE Computer Society Conference on Pattern Recognition and Machine Intelligence", Princeton, April 13, 1978.

Kanal, Laveen N. , Lectures on Problem Solving and Pattern Recognition, Vrije Universiteit, Amsterdam, May 10, 17, 24, 1978; continuation lecture at Delft Institute of Technology, June 1, 1978. These lectures were attended by 30-35 students and faculty representing various universities and institutes in Holland.

Kanal, Laveen N., Invited talk "Pitfalls in Applying Pattern Recognition Techniques in Practice", special symposium American Chemical Society, Northeastern Meeting Boston, Mass., June 27, 1978.

Kanal, Laveen N., "On the Design and Evaluation of Medical Diagnosis Models", invited presentation at special symposium, Intern. Conf. on Cybernetics & Soc., Tokyo, Nov., 1978.

Kanal, Laveen N., Admissible Search Strategies for Parametric and Nonparametric Hierarchical Classifiers," presented at Fourth IJCPR, Kyoto, Nov., 1978.